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MET O 3 TECHNICAL NOTE NO. 24

THE ESTIMATION OF MEAN TEMPERATURE FROM DAILY MAXIMA AND MINIMA

by

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Summary

Departures from the true mean temperature of the average of daily maxima and minima are shown to depend on the combined effects of radiation and advection. In Britain, systematic errors are generally less than 0.3°C, but pronounced seasonal and geographical variations are caused by changes in radiation, and in the relative importance of advection. Differences between 12 hour maxima and minima read at 09h and 21h and 24 hour values read at 09h are also investigated, and found to vary seasonally but not geographically.

1. Introduction

Mean temperatures are often calculated from the average of daily maxima and minima. This is clearly convenient, since at many stations more frequent observations, from which more reliable estimates could be made, are not available. It is clearly important, however, to have some knowledge of the errors introduced by such a procedure.

Synoptic automatic weather stations currently being introduced by the Meteorological Office record 24 hourly observations of temperature, but not maxima or minima. Since the true mean temperature is very closely approximated by the mean of 24 hourly observations, there will be no difficulties in obtaining mean temperatures for such stations. It will be important to know, however, how these compare with values derived from the averages of maxima and minima.

The problem of estimating the true mean temperature has been investigated many times before. Brooks (1921) undertook a global appraisal, but rather than quoting errors associated with the use of maximum and minimum, concentrated on finding a combination of hourly observations which gave better estimates of the true mean temperature. For the UK, he suggested a weighted mean of temperatures observed at 07h, 13h, and 21h, these being the times at which observations were frequently made in those days. Baker (1975) has shown that the errors in using daily maxima and minima depend upon the time at which the observations are made. If this is close to the time of the minimum, then an underestimate of the mean is made, while if it is close to the time of the maximum, then an overestimate is obtained.

WMO recommend taking the mean of the day maximum in the period 09-21h and the night minimum in the period 21-09h, and, in the UK, this practice is followed at stations manned by Meteorological Office staff. At the 480 or so voluntary climatological stations observations are only made once per day at 09h. An investigation of the differences between 12 hour (09-21 and 21-09) and 24 hour (09-09) maxima and minima based on 38 stations in the period 1957-70 was reported by the Meteorological Office (1976). It was found that differences in the summer were small, but that in the winter the 24 hour values were more extreme, with a difference of 0.4°C for the maxima and 0.7°C for the minima. Unpublished work in the Meteorological Office based on 14 stations in the period 1957-70 also investigated errors in the estimates of the mean of 24 hourly observations obtained by averaging the daily maxima and minima. In summer, both 12 hour and 24 hour maxima and minima were found to overestimate the mean by 0.2°C. In winter, the 12 hour maxima and minima gave good estimates of the mean, while the 24 hour values gave means which were 0.2°C too low. The results were stated to be similar for all the stations examined.

The present investigation essentially repeats the earlier Meteorological Office work using data from 15 stations for 1961-80. The broad results are confirmed, but the factors responsible for producing the departures from the true mean temperatures are discussed, and these are used to explain a substantial geographical variation which was not revealed in the previous analysis.

2. Differences between the mean of 24 hourly temperatures and the average of daily maxima and minima

The departure of the mean of maximum and minimum from the true mean will depend upon the distribution of temperature in a 24 hour period. If the temperature spends more time near the minimum than the maximum, ie the distribution is positively skewed, then an overestimate of the mean is made. If the skewness is reversed, then an underestimate is obtained. On any given day, the sequence of hourly temperatures will depend upon the combined effects of radiation and advection. It is changes in radiation and in the relative importance of advection which are responsible for the seasonal variations in the errors of mean temperature, and for the differences obtained from the use of either 12 hour or 24 hour values of the maximum and minimum. The relative importance of advection, however, will also be greater on coasts than inland, and in the North West of Britain than in the south east. This leads to the expectation that there may be geographical variations in the errors of the estimates of mean temperature. These expectations are confirmed by the analysis.

The distribution of the 15 stations used is shown in fig 1, and results are presented for two groups of stations. The first - Ringway, Elmdon, Heathrow, Waddington, and Boscombe Down - represent inland stations in England, while the second - Lerwick, Wick, Stornoway, Tiree and Valley - represent coastal sites in the north west of Britain. Let Δ_9 denote the departure from the true mean of the mean of the 24 hour maxima and minima recorded at 09h, and Δ_{DN} the departure from the true mean of the day maxima and night minima recorded at 21h and 09h respectively. The true mean is obtained from the average of 24 hourly observations of temperature. Monthly values of Δ_9 and Δ_{DN} are presented for the two

groups of stations in fig 2, and their distributions are seen to be quite different. At inland stations a bimodal pattern emerges, with values exceeding 0.2°C in spring and autumn, and falling to near zero in winter. At the coastal sites, a simpler distribution, with a summer maximum and winter minimum emerges. For both groups of stations, Δ_g is similar to Δ_{DN} in summer, but lower in winter.

3. The effects of radiation and advection

3.1 Radiation

The effects of radiation are well represented by the distribution of mean hourly temperatures, since advective effects will be self-cancelling. At coastal stations, any advective effects with a regular diurnal cycle, eg the sea breeze, will also be included, but this is not important in terms of a qualitative explanation of the observed behaviour of Δ .

The radiation received from the sun is proportional to the sine of the solar elevation, and is therefore more sensitive to solar elevation when the sun is low in the sky than when it is high. Thus the maximum temperature in winter will be more sharply defined in winter than in summer, and this is illustrated in fig 3, which displays the mean hourly temperatures at Heathrow during June and December for 1961-80. In December, the temperature spends more time near the minimum than the maximum, the true mean is overestimated from the mean of the maximum and minimum, and Δ is positive. In June, the skewness of the temperature distribution is less marked, but is in the opposite sense, and Δ assumes a small negative value. The seasonal variation in Δ which is caused by radiation is illustrated schematically in fig 4a. For most of the year, the

minimum is flatter than the maximum, giving positive values of Δ, and negative values are restricted to June and July. The effects of radiation at coastal sites are similar, but the seasonal variation is less marked, and Δ is close to zero in June and July.

3.2 Thermal advection

The effects of steady thermal advection are illustrated in fig 5, where advective temperature changes of 1 C every 2 hours, ie 12°C in 24 hours, have been superimposed onto the mean hourly temperatures for December at Heathrow. Thus, for the warm advective case, the sequence of hourly observations has been constructed by subtracting 6°C from the mean for 09z, 5.5°C from the mean for 10z, 5°C from the mean for 11z, and so on, finally adding 6°C to the mean for 09z the next day. The true mean temperatures for these occasions are therefore the same as in fig 3, but the skewness of the distribution of hourly temperatures has been radically changed. The cold advective case in particular shows that the minimum is sharper than the maximum, with a consequent underestimation of the true mean (negative Δ). The warm advective case, although less obvious from the diagram, also has a negatively skewed distribution of hourly temperatures and produces the same negative value of Δg as the cold advective case. The difference between the cases is that in the cold advective situation, both the 12 hour and 24 hour maximum and minimum are recorded at 09h, whereas with warm advection, the 12 hour values are recorded at 21Z. The mean of the 12 hour maximum and minimum is therefore the 21z temperature, and this is close to the true mean.

This is because the mean temperature at 21z is close to that for the day in fig 3 (the 21z and daily mean temperatures in fig 5 are the same as those in fig 3).

In winter, therefore, the effects of thermal advection oppose those of radiation, and produce underestimates of the true mean. The effects are greater for 24 hour than 12 hour maxima and minima. In summer, advective effects are small for two reasons. Firstly, thermal contrasts between air masses in summer are less than in winter, while the diurnal variation caused by radiation is much stronger. The result is that maxima and minima are rarely observed at 21z or 09z in summer; in winter, this is not uncommon. Secondly, the observing hour of 09z is close to the minimum in winter but not in summer. The results found by Baker (1975), that the errors in the true mean obtained from 24 hour maxima and minima depend on the observing hour, are due to advection. If the observing hour is close to the time of the minimum (eg 09z in winter) one effectively has the choice of two minima; if it is close to the time of maximum, one has the choice of two maxima. If the observing hour is mid-way between maximum and minimum (eg 09z in summer or 21z at any time) then the effects of advection are minimised. The seasonal variation in the contribution of advection to Δ are illustrated in fig 4b.

3.3 Variations in cloud cover

The effect of variations in cloud cover on the distribution of hourly temperatures are caused by both advection and radiation. The change in cloud cover may well be caused by advection, but the response of the temperature will depend upon the radiation balance at the time the change occurs. Consider a 3 hour cloud clearance in

winter, for instance. If it occurs around midday, a slight rise may be produced, but in the long hours of darkness, it will cause a fall. This will cause a sharp minimum to be produced, and so the mean temperature will be underestimated (negative Δ). In general, sensitivity to radiation is greatest at night in winter (which produces negative Δ) and in daytime in summer (which produces positive Δ). The contribution to Δ caused by variations in cloud cover is therefore negative in winter and positive in summer, and this is illustrated in fig 4c.

3.4 Combined effects

The combined effects of radiation, thermal advection, and variable cloud cover on Δ can be obtained from an addition of the curves displayed in figs 4a, 4b,and 4c and a qualitative explanation of the results presented in fig 2 is now clear. At inland stations, where radiation is relatively important, Δ is generally positive. The bimodal distribution is caused by the summer trough for radiation being sharper than the summer peak for advection and variable cloud cover. Although the response to variations in cloud cover is essentially radiative, they will occur most frequently where advective changes are common. Consequently, where advection is important, the greater weight attached to the curves in figs 4b and 4c produces a relatively simple distribution of Δ , with positive values in summer and negative values in winter. The differences between Δ_9 and Δ_{DN} are caused by the greater advective effects in winter, and which are mainly due to the close proximity of the observing hour (09) to the time of minimum temperature.

Application of these results rests on a knowledge of the extent to which the 'inland' or 'coastal' set of figures applies to any given station. The difference between the two sets may be quantified by the difference of the values of Δ in June and July from those for the whole year. This has a correlation of -0.84 with the mean annual diurnal range and -0.92 with the standard deviation of the monthly mean values of the diurnal range. This latter quantity decreases to the northwest more rapidly than the diurnal range itself. The high correlation must be considered suspect because of the difficulty of distinguishing between coastal effects and distance to the north west - no coastal stations in the south east or inland stations in the north west were used. Nevertheless, the standard deviation of the diurnal range probably offers a reasonable means of deciding how the values of Δ pertaining to a particular station compare with the two sets presented in fig 2. A generalised map of the standard deviations of the mean monthly values of diurnal range, based on nearly 600 stations in the period 1951-80, is presented in fig 6. The quoted values of Δ for the sets of inland and coastal stations are associated with standard deviations of 1.4°C and 0.5°C respectively. Fig 6 therefore shows that values of Δ associated with a standard deviation of 1.4°C are probably representative of a large proportion of the country, while those associated with a standard deviation of 0.5°C are likely to be restricted to the more exposed costal sites in the north and west.

The difference between the true mean and that obtained from the maximum and minimum on any given day may, of course, vary widely from the values presented above. The standard deviation of both Δ_g and Δ_{DN}

in all months is around 0.5°C. The assumption that there are 10 independent values in 31 daily measurements of temperature, suggests that the standard errors to be attached to the quoted values of Δ is around 0.03°C, but that the standard deviation of Δ for individual months is 0.16°C.

4. Differences between 12 hour and 24 hour maxima and minima

Thermal advection and variable cloud cover are responsible for introducing the differences between the 12 hour (09-21 and 21-09) and 24 hour (09-09) maxima and minima. Fig 7 shows that the differences are greater in winter than in summer, and for minima than maxima; these features may be attributed to the dominance of radiation in summer and the proximity of the observing hour (09z) to the time of minimum temperature in winter. Geographical variations in these differences may be anticipated. The greater importance of advection on northwestern coasts contributes towards larger differences there than elsewhere, but this is counteracted by the greater radiative response to variable cloud cover at inland sites, especially for minima in winter. As a consequence, differences between maxima are likely to be largest on northwestern coasts, while in winter, differences between minima are likely to be greatest inland. While such geographical variations are present and are indicated in fig 7, the effects are generally small, and do not assume any great practical importance. The findings of the Meteorological Office (1976) concerning the differences between 12 hour and 24 hour maxima and minima are therefore confirmed, both in respect of the size of the differences attained and in the relative absence of geographical variations.

5. Conclusions

The difference between the mean of daily maxima and minima and the true mean temperature has been shown to depend on the effects of radiation and advection. The regular diurnal variation of radiation causes the mean of the maximum and minimum to overestimate the true mean in winter, but these differences are generally opposed by the effects of thermal advection. Irregular variations in cloud cover cause the true mean to be overestimated in summer but underestimated in winter. The combined effect of these factors depends on the relative importance of advection, and this varies widely with location. Where radiation is relatively important, as in inland stations in the South Eastern half of Britain, the departure of the mean of day maximum and night minimum from the true mean undergoes a bimodal seasonal variation, with maximum differences around +0.2°C in spring and autumn. Where advection is more important, differences range from +0.2°C in summer to -0.2°C in winter. The relationships previously found between 12 hour and 24 hour maxima and minima were confirmed, with only small geographical variations evident.

References

Baker, D. G. 1975 Effect of Observation Time on Mean Temperature Estimation. J. Appl. Met., 14, 471-476.

Brooks,C.E.P. 1921 True Mean Temperature. Monthly Weather Review, 49, 226-229.

Meteorological Office 1976 Averages of temperature for the United Kingdom 1941-70. Met O 883, HMSO, London.

FIG 1 - DISTRIBUTION OF STATIONS

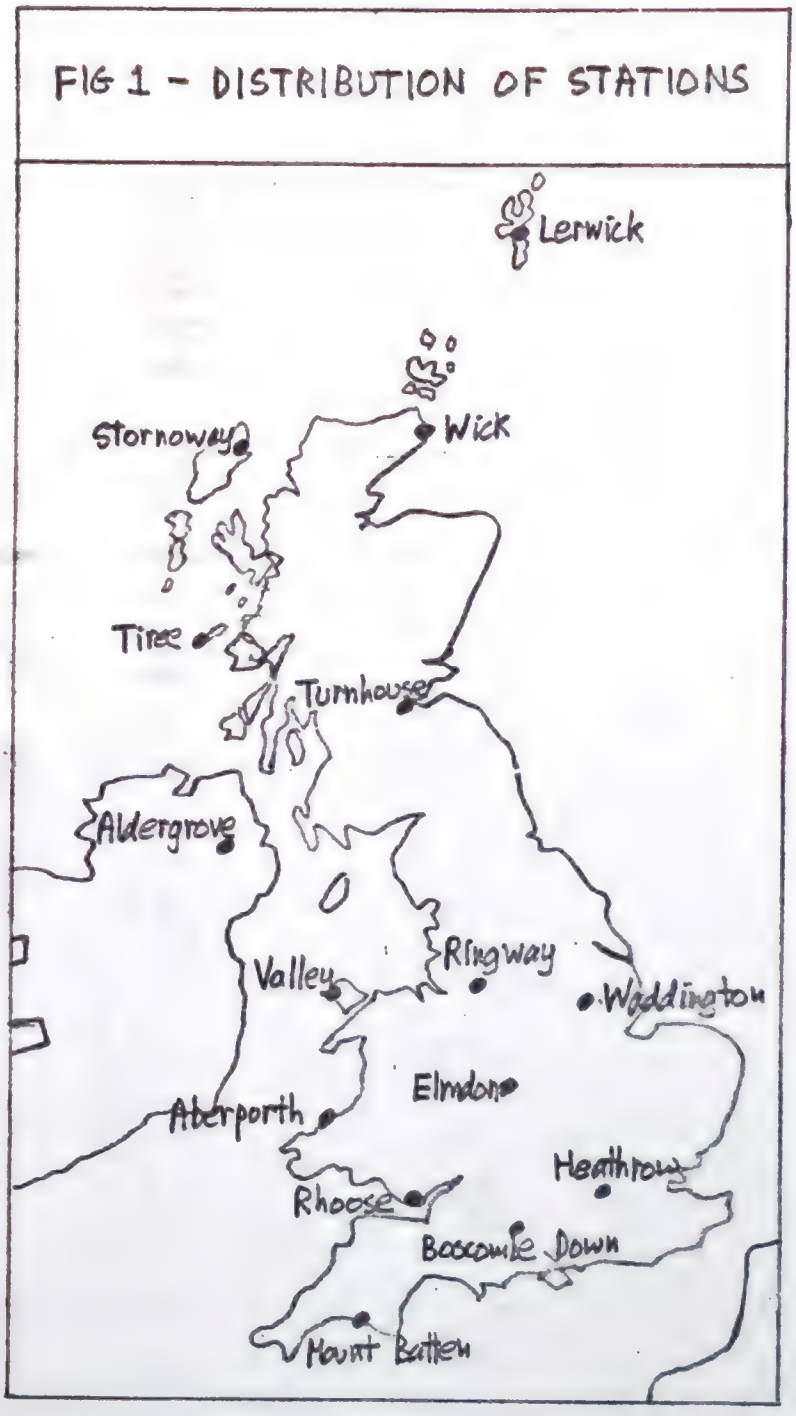


FIG 2 - THE DEPARTURE (Δ) OF THE MEAN OF MAXIMUM AND MINIMUM TEMPERATURES FROM THE TRUE MEAN

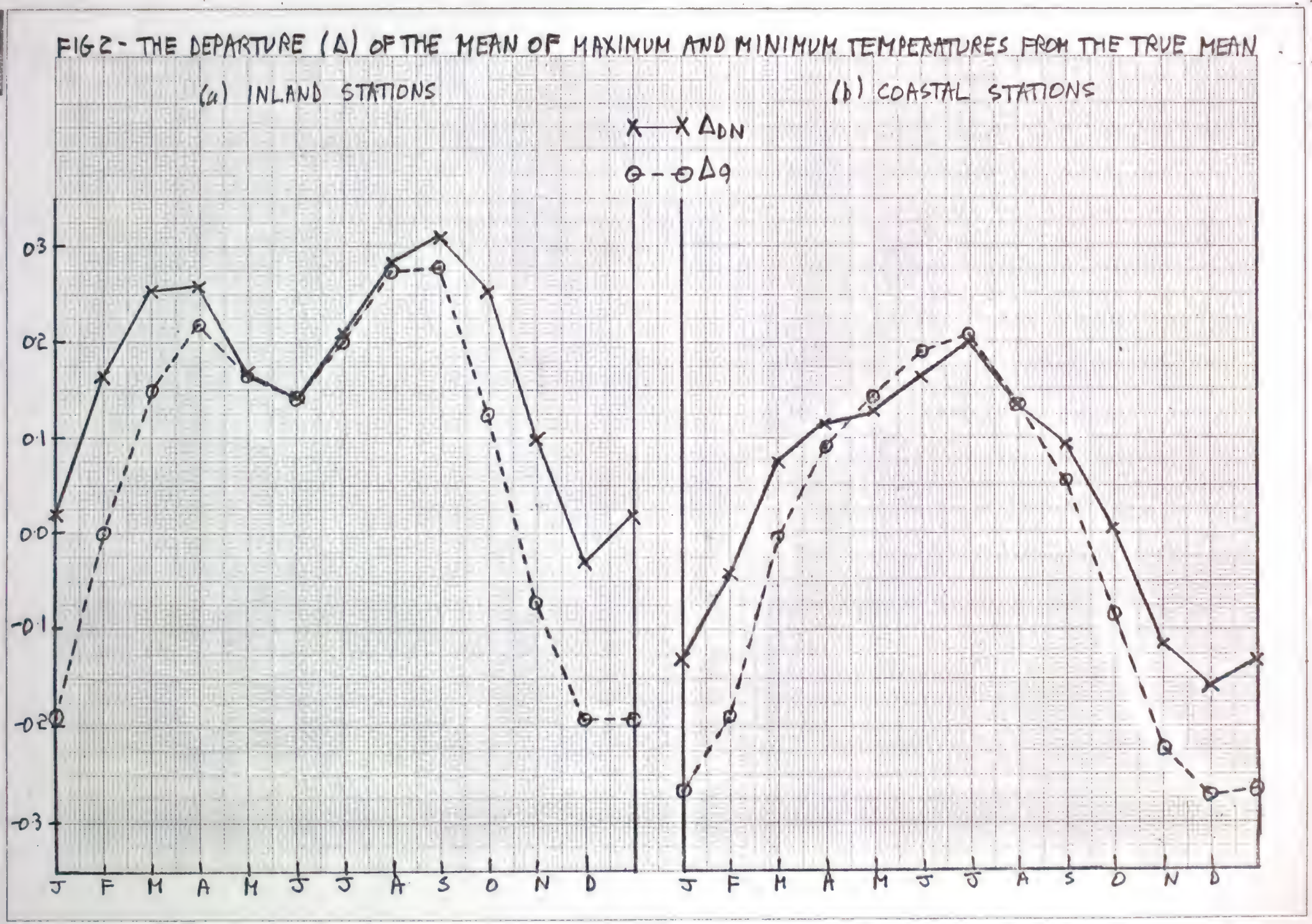


FIG3 - MEAN HOURLY TEMPERATURES AT HEATHROW FOR 1961-80.

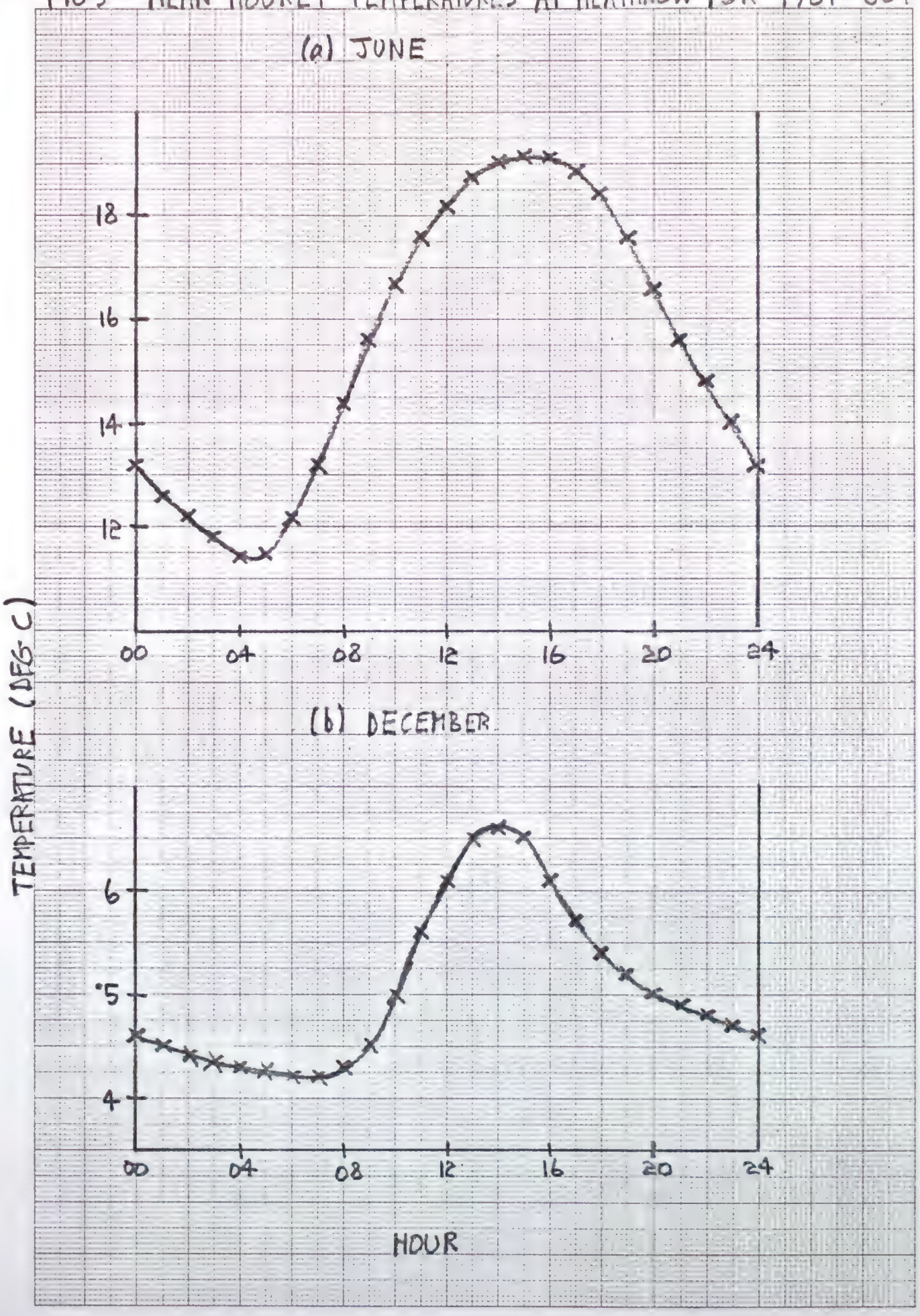
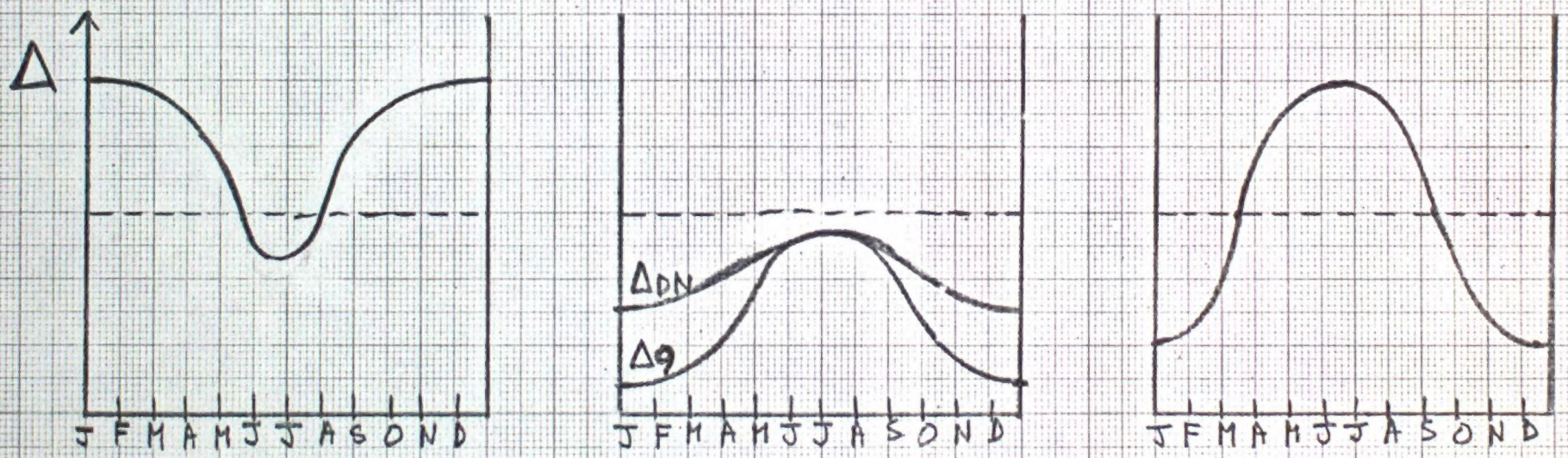


FIG4 - CONTRIBUTION OF RADIATION, THERMAL ADVECTION, AND VARIABLE CLOUD COVER TO Δ.



(a) RADIATION

(b) THERMAL ADVECTION

(c) VARIABLE CLOUD COVER

FIG 5 - STEADY THERMAL ADVECTION IMPOSED ON MEAN HOURLY TEMPERATURES FOR DECEMBER AT HEATHROW

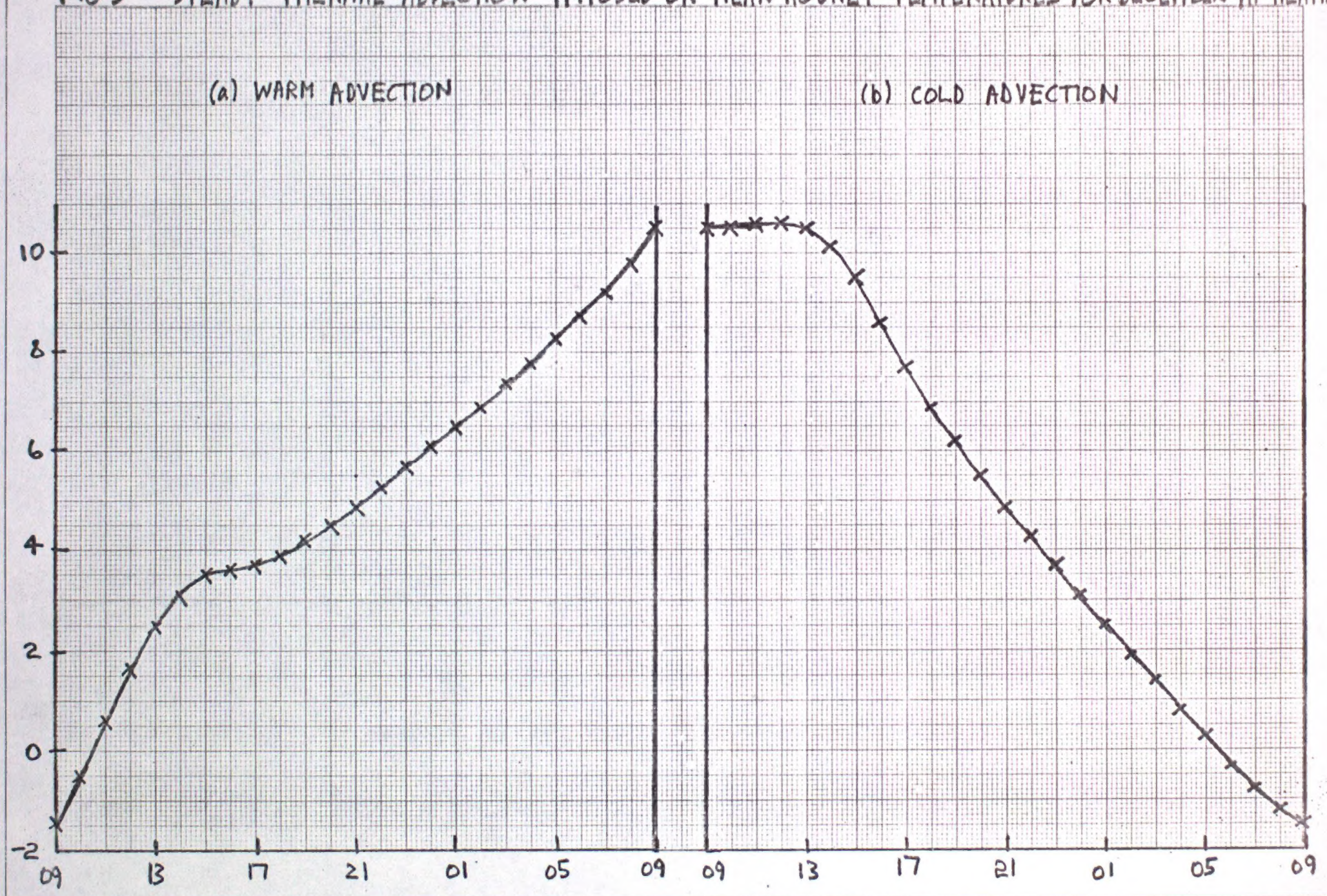
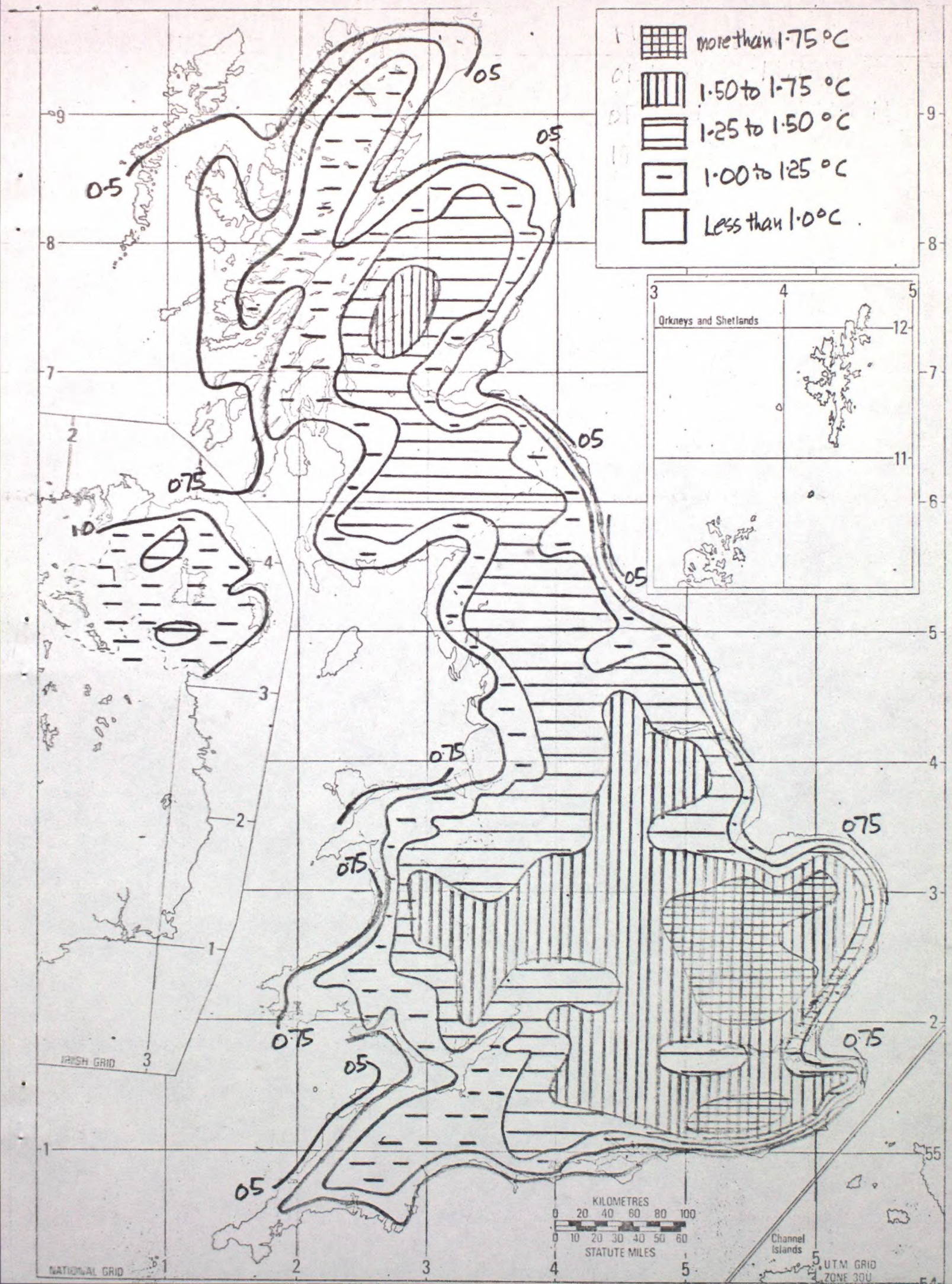


FIG 6 – STANDARD DEVIATION OF MONTHLY MEAN VALUES OF DIURNAL RANGE FROM 1951 TO 1980.



Chartwell

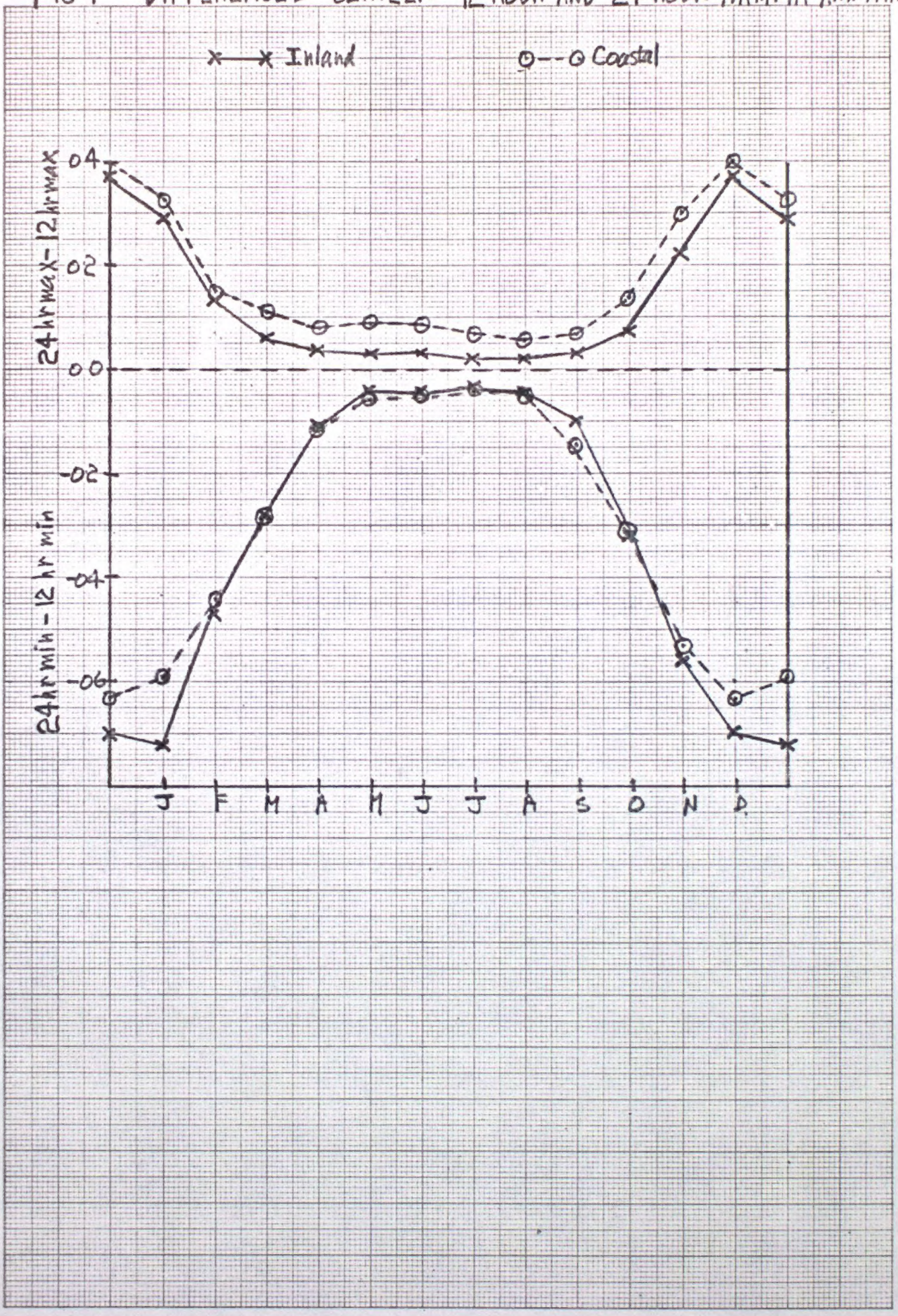



FIG7 - DIFFERENCES BETWEEN 12 HOUR AND 24 HOUR MAXIMA AND MINIMA.